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FINAL PROGRESS REPORT

A TEST OF COLOR PHOTOGRAPHY FOR DETECTING MOISTURE STRESS AND PREDICTING LEAF ABSCISSION IN BROADLEAVED VEGETATION 1/

by

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Seattle, Washington 98105

1/ Sponsored by Advanced Research Projects Agency, ARPA Order 818

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A TEST OF COLOR PHOTOGRAPHY FOR DETECTING MOISTURE STRESS AND PREDICTING LEAF ABSCISSION IN BROADLEAVED VEGETATION [1/]

Prepared by:

George R. Fahnestock 6/9/70

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FINAL PROGRESS REPORT SUMMARY

A TEST OF COLOR PHOTOGRAPHY FOR DETECTING MOISTURE STRESS AND PREDICTING LEAF ABSCISSION IN BROADLEAVED VEGETATION

Vegetation in five greatly differing vegetation types, widely separated geographically, was photographed with Kodachrome II and Ektachrome Aero Infrared film at intervals between late August and early November. Selected points on the photographs were evaluated by means of the Munsell Color System to see whether changes due to moisture stress or imminence of leaf abscission could be detected. Mean ratings for hue, value, and chroma on Kodachrome followed seasonal trends, and so did ratings of value and chroma on infrared film. Variation in moisture stress, as indicated by the Buildup Index factor of fire danger rating, was rather small except at one location. No relation of color change to Buildup Index could be detected. No color change could be attributed to impending leaf abscission. Therefore, it appears unlikely that colorimetric detection and measurement of moisture stress in living vegetation is possible.

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The author is most grateful to personnel of four National Forests for contributing their time to locate suitable study sites, plan the work, and take the photographs. Those most involved in the work, and their contributions were:

Ouachita National Forest, Arkansas
Planning and supervision - L.L. Davis, Fire Control Officer; Carlton Robards, Forest Dispatcher; David F. Jolly, District Ranger, Mena; O.D. Smith, Assistant Ranger, Mena.
Photography - O.D. Smith, Jr., and Shirley Sirmon, Towerman.

National Forests in Mississippi
Planning and supervision - E.H. Collins, Fire Control Officer; Herbert P. Rice, District Ranger, Delta.
Photography - Herbert P. Rice.

Kisatchie National Forest, Louisiana
Planning and supervision - June Terry, Forest Dispatcher.
Photography - W. Don Blackburn, District Ranger, Evangeline.

Pisgah National Forest, North Carolina
Planning and supervision - George S. Gibbs, Staff Officer; Frank O. Parker, Jr., Assistant Ranger, Toecane.
Photography - D.H. Carmichael, District Ranger, Toecane Frank O. Parker, Jr.

Matching points on the transparencies with standard color chips was a most tedious and eye-straining task; the consistency of results indicates it was done well. Credit for this accomplishment goes to two temporary aides and the secretary of the Fuel Appraisal Systems Project. Gerald Bryson, an undergraduate student at Seattle Pacific College, selected the comparison points; and he and Mary E. Joss, the secretary, made color determinations for all points. Norton R. Munn, Jr., organized and labelled the slides and made color determinations for the Seattle area. Bryson also made most of the statistical analyses.

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PROBLEM

The quantity of forest fire fuel available to burn increases with drought. Coarse fuel particles and deep, compact fuel beds become flammable. Some living vegetation dies; some, although still alive, becomes readily ignitible under certain environmental conditions; and much becomes sufficiently dehydrated that it offers little deterrence to the spread of fire. In warm climatic zones some or all deciduous species lose their leaves in response to drought, genetic characteristics, or other influence whose presence, unlike frost in higher latitudes, is not easy to identify. The fallen leaves are an important, frequently the most important, fuel component.

There is urgent need for a reliable, consistent, broadly applicable, easily used technique for recognizing and delineating the extent of drought, especially its extreme stages. The technique would have immediate utility for appraising fuel availability on going fires, relating fuel hazard to weather for various levels of fire control planning, and indicating level of general preparedness needed. It appears possible that some form of remote-sensing can partially or wholly fill the need.

LITERATURE REVIEW

The moisture content of living foliage tends to follow a characteristic seasonal pattern. New leaves are extremely moist, often with more than 200 percent moisture content (ovendry basis). After the leaves harden, a considerably lower moisture content persists through the growing season and, in evergreen species, into the subsequent season(s) (Blackmar and Flanner 1968, VanWagner 1967, Reifsnyder 1961, Wendel and Storey 1961). The usual summer drought apparently has no effect on foliage moisture content in western conifers 1/ (Jameson 1966), but some shrubs, notably chamise (Adenostoma fasciculatum H. and A.) dry to about 50 percent without dying (Dell and Philpot 1965). A few observations have suggested that moisture level is more responsive to drought in deciduous hardwood foliage than in evergreen, that the response is quite large in some species, and that it may be accompanied by wilting and/or marginal necrosis (Fahnestock 1962).

The systems used for measuring forest firedanger in the United States incorporate a component, usually called "buildup index" that attempts to account for the effect of cumulative drying on dead fuels, such as forest floor materials 3 to 6 inches deep and wood ≤ 3 inches in diameter (USDA Forest Service 1964, 1968). Proposed, but

1/ The author found essentially the same moisture content in September as in June in nine northern Rocky Mountain species.

not in use, is a drought index for gauging the response of larger wood and deeper organic accumulations to continued moisture deficiency (Keetch and Byram 1968). Both indexes are calculated by means of bookkeeping that interrelates rainfall and day-by-day drying conditions; thus both are tied to continuously operated weather stations and consequently cannot sharply delineate areas that their current readings represent. Buildup index and drought index unquestionably have some potential for indicating moisture content of living fuels, but these have not been developed to the point of practical utility.

Some way of directly detecting moisture level in vegetation, by means of generally available technology, would eliminate need for cumbersome bookkeeping, uncertainties of inference regarding complex plant-environment interaction, and dependency on fixed stations of questionable representativeness. Conceivably measurement of color change in massed or individual plants could be a suitable technique. Ektachrome Aerographic Infrared Film, Type 8443, also called camouflage detection film, shows diseased and detached foliage in colors contrasting with that of healthy foliage because of a change in infrared reflectivity (Smith and Anson 1968). The change results from loss of turgidity in the leaf mesophyll, presumably accompanied by general reduction in moisture content. It appears logical to believe, then, that infrared photography should detect any considerable reduction in moisture regardless of cause. A recent study tested this hypothesis on three conifers and two evergreen hardwoods grown in a green house. 2/ Wilting was visible before any color change on infrared film, possibly because photography was taken by artificial light or poor sunlight.

Studies at the National Bureau of Standards have provided some background for colorimetry of living vegetation at wavelengths $\leq$ 1,000 millimicrons. Detached leaves of a white oak tree (Quercus alba L.) gradually changed color with time from green toward red (Keegan, Schleter, and Hall 1955). The color change began immediately in leaves that were kept dry but was delayed about a week in leaves immersed in water. In terms of the Munsell color system (Billmeyer and Saltzman 1966, Munsell Color Co.), wet leaves changed hue much more rapidly than dry leaves for several months after detachment; e.g., hues at 10 weeks were 0.2 YR for wet leaves and 0.9 GY for dry. During the same period, value for wet leaves decreased from 3.3 to 2.4, indicating slight darkening; but for dry leaves, value increased from 3.3 to 4.4, indicating somewhat greater lightening. Grayness increased in both wet and dry leaves, but more in wet, as shown by decreases in chroma from 2.5 to 0.6 (wet) and 2.5 to 1.9 (dry) in 10 weeks. Greatest spectral reflectance change was in the visible spectrum between 670 and 680 millimicrons (chlorophyll band) for dry

2/ Fritschen, Leo J. Plant water stress as indicated by near-infrared reflectance. Univ. Wash., Coll. Forestry unpub. rep., 18 pp. 1967.

leaves but in the near infrared between 750 and 900 millimicrons for wet (i.e., increasingly saturated) leaves. The changes were large enough that aerial photography in the indicated wavelength regions should be usable to estimate roughly how long foliage has been detached from trees.

Photographic color transparencies using portionsof the visible spectrum tend to change with exposure in lightness and saturation, with constant hue, except that red and green emulsion layers change in hue also (Keegan, et al. 1957). In particular, overexposures are weaker in color than normal exposure, i.e., higher in value, by the Munsell system. Hue shifts very slightly toward the red end of the spectrum in shade as opposed to full sun, but value and chroma do not change. The hue of close-ups appears to shift from yellow toward blue as compared with photography from a greater distance.

Leaves in summer condition tend to have middle yellow-green Munsell hues, with the dorsal side more yellow than the ventral (Keegan, et al. 1956). In leaves affected by frost or lateness of the season, the dorsal surface is more red (from yellow) than the ventral. Value is higher on the dorsal surface of leaves in all conditions. Chroma also is higher on dorsal surfaces of summer-green leaves, but there appears to be no difference between surfaces of fall-colored leaves.

The NBS findings indicate that conditions of light and shade are not critical for colorimetric photography of vegetation, and that exposure strongly affects only lightness (Munsell "value"). There is an implication that color change attendant on drying should be detected best within the visible spectrum, therefore that natural-color film should be superior to false color, which appears to cast doubt on commonly held opinion as to the capabilities of infrared photography. Rather voluminous literature indicates, however, that the relative merits of natural- and false-color films for detecting moisture stress are far from clearcut (Murtha 1969).

Drying of detached foliage causes large increases in spectral reflectance near 1.55, 2.05, and 2.50 m. (Olson 1967). However, these wavelengths are outside the sensitivity range of infrared photographic film and, presumably, could be detected only by more sophisticated, less available sensors.

PURPOSE AND SCOPE

An exploratory study was made to determine whether vegetation changes color detectably in response to drought and to impending seasonal loss of foliage. Interest centered on the occurrence of changes large enough and consistent enough to be detected by simple operational techniques rather than on the nature of and reasons for the changes. Photography was used as the observational medium because it (1) could make the observations more quickly than any other means, (2) would be free of observer bias, (3) provided a permanent record that could be interpreted by more than one person, and (4) would probably be the medium used for aerial surveillance to detect drought effects over large land areas. One natural color and one false color film were used to represent media readily available to all potential users. Photography was obtained during only one year--1967.

METHODS

In general, the study consisted of taking panoramic and moderately close-up photographs of predominant broadleaved, deciduous vegetation at five locations in the United States under varying conditions of moisture stress and comparing colors of designated objects with a standard color system. The locations included a diversity of vegetation types, basic climates, and expected weather patterns. Photographs were taken from the ground by employees of the U.S. Forest Service using several different kinds of 35 mm. still cameras. Color interpretations were made in Seattle, Washington, by employees of the Fuel Appraisal Systems Project, Pacific Northwest Forest and Range Experiment Station.

Study Sites

In accordance with the original plan, photography was taken at three sites in the mid-South and one in the Southeast. Differences in expected moisture regimes were the main basis for selection. The differences were expected to result from topographic situations, soil types, and regional weather patterns. The concern was not so much to sample different weather patterns as to be reasonably sure that at least one site would experience a considerable degree of drought during the season. A fifth site near Seattle, Washington, was added to take advantage of a record drought that was quickly relieved by moderate rain. The study sites and their general characteristics were as follows:

1. Rich Mountain--Ouachita National Forest, approximately 10 miles northwest of Mena, Arkansas; elevation 1,125 feet; forest type chiefly oak hickory with an admixture of shortleaf pine and more mesophytic hardwoods; soil rather shallow; area frequently subject to severe late summer-early fall drought.

2. Delta Tower--Delta National Forest, about 10 miles southeast of Rolling Fork, Mississippi; elevation about 100 feet; soil deep alluvium, mostly heavy; timber type bottomland hardwoods; summers moist, fall and early winter sometimes quite dry.

3. Woodworth Tower--Kisatchie National Forest, 12 miles south-southwest of Alexandria, Louisiana; elevation about 150 feet; soil deep, sandy; timber type slash and loblolly pine with some admixture of oak; summers usually moist but with occasional, rather long rainless periods, and late fall occasionally quite dry.

4. Green Knob--Pisgah National Forest, 21 miles east-northeast of Asheville, North Carolina; elevation 5,000 feet plus; soil rather shallow; vegetation Appalachian hardwoods with some admixture of conifers and some evergreen understory species; usually moist year-round but with very occasional dry falls.

5. Seattle--a backyard 10 miles north of the center of town and a hilltop clearing 5 miles farther northeast; elevations 200 to 300 feet; soil deep, droughty glacial deposit; vegetation mixed conifer-hardwood with broadleaved understory; summers usually dry.

Photography

Film and processing.--Twenty-exposure rolls of 35 mm. Kodachrome II and Ektachrome Aero Infrared Type 8443 film were used. 3/ All the film of each type came from a single batch. The full season's supply was air-mailed from Seattle to each other study location at once and was kept refrigerated before and after exposure. All exposed film from each location was mailed back to Seattle at the conclusion of the season's observations and was again held under refrigeration until all film from all locations had returned. The Kodachrome was processed in one batch by the Palo Alto, California, processing laboratory of Eastman Kodak Company, and the Ektachrome infrared was processed in one batch by Charles Conkling and Sons, Inc., Portland, Oregon. The developed film was mounted in the form of standard 2" x 2" slides.

Equipment.--Five different types of cameras were used; their specifications, as far as they are known, follow:

1. Rich Mountain--Konica FM 52 mm. f.14 lens
2. Delta Tower--Kodak "Signet"
3. Woodworth Tower--Amica "Eyelux" 45 mm. f.1.8 film lens
4. Green Knob--Retina 4
5. Seattle--Two Honeywell "Pentaxes", 55 mm. f2 and f2.2 lenses

3/ Use of proprietary names does not imply Government endorsement of the products.

A skylight filter was used with the Kodachrome II film and a Wratten 12 or equivalent (yellow) filter with the Ektachrome infrared, in accordance with manufacturers instructions. Each photographer used an exposure meter to which he was accustomed.

Subjects.--Ten or eleven subjects were photographed at each site. The standard was four panoramic shots in specified directions and six moderate close-ups of specific plants or groups of plants. However, Seattle was short one panoramic shot and had two extra close-ups, Green Knob had an extra panoramic shot, and Delta Tower had an extra close-up. Except for Woodworth Tower, the panoramic shots contained chiefly hardwoods, and all close-ups except one at Seattle were of broadleaved species. Two or three close-ups at Green Knob contained evergreen shrubs; all other close-ups at all locations were of deciduous species. Roadside spraying with herbicides destroyed some of the close-up subjects at Delta Tower in October. Appendix A lists the specific subjects of photography at each site.

Conditions of photography.--Instructions (see example, Appendix B) called for taking photographs between 1000 and 1400 hours on days when the atmosphere was not hazy, and cloud shadows covered no more than 25 percent of any panoramic view. The specifications with regard to time of day and cloud cover could not always be met, but most of the photography was taken under quite favorable conditions. At the southern sites, an effort was made to obtain photography on a day with low buildup index (USDA Forest Service 1964) in August, on one or more days with high buildup in September and October, and again after heavy rain in the fall. A final round of photography was to be taken when, in the observer's judgement, leaf fall was imminent, and also at Green Knob when fall color of the foliage was at its height. Contrary to expectation, no southern site experienced any degree of drought during 1967. However, a record drought in the Pacific Northwest, which was relieved by rain early in September long before normal leaf fall, gave an unexpected opportunity for photographic evaluation. Table 1 shows the conditions under which photography was taken.

Color Evaluation: Viewed Slides

Color comparison points were selected and most color evaluations were made by means of an "Agfascop" table-top viewer. A 7 x 10-square rectangular grid was inserted in the viewer just above the slide for use in identifying comparison points. Three points were selected for evaluation on each view at each study site. Criteria for selection were good lighting, essentially solid color over an area the size of a grid square, color representative of healthy vegetation common in the area of the view, and recognizability on all repetitions of the same view (see Appendix C). Alphanumerical designators of grid squares to be evaluated for each date were tabulated before interpretation began.

Table 1.-- Conditions when photographs were taken

Location and date	Time (start)	Visibility	Cloud Cover	Build-up	Fine Fuel m.c.	Last rain ≥ .2 in.
	Hours	Miles	Percent			Date
Rich Mountain:						
Aug. 20	1130	10	50	30	16	Aug. 19
Aug. 28	1035	15	0	20	15	Aug. 23
Oct. 12	1300	8	0	44	11	Oct. 8
Oct. 18	1340	20	0	6	10	Oct. 17
Nov. 8 1/	1330	8	30	14	11	Nov. 3
Delta Tower:						
Sept. 18 2/	1030	10	90	30	15	Sept. 8
Sept. 22 2/	1330	10	10	38	15	Sept. 8
Oct. 21	1330	20	0	53	9	Oct. 17
Nov. 6 3/	1330	Unlimited	0	44	8	Oct. 31
Woodworth Tower:						
Aug. 29	1240	12	15	3	17	Aug. 27
Sept. 26	1130	10	10	41	17	Sept. 22
Oct. 23	1230	12	5	38	12	Oct. 16
Nov. 2	1300	12	0	6	8	Oct. 30
Nov. 6 3/	1000	12	5	12	8	Oct. 30
Green Knob:						
Sept. 6	1230	Unlimited	10	12	19	Sept. 1
Sept. 22	1200	5	10	26	16	Sept. 21
Oct. 4	1315	Unlimited	20	9	15	Sept. 28
Oct. 23	1330	5	4/ 20	11	15	Oct. 18
Seattle: 5/						
Sept. 1	1330	5	Variable	221	5	June 22
Sept. 12	1415	5+	<10	15	10	Sept. 11

1/ Panoramic views only; close-up foliage fallen. Not used in analysis.
2/ Infrared on Sept. 18, Kodachrome on Sept. 22.
3/ Killing frost Nov. 4, 5, and 6; minimum temperature 29°F.
4/ Cloud cover > 25% for close-ups.
5/ Weather and fire danger data from USFS North Bend Ranger Station, 30 miles east.

Two interpreters made color evaluations for all areas and a third interpreter made evaluations for Seattle only. The practice was to hold a Munsell color chart over the slide viewer in such a way that the comparison point was visible through the perforation in the chart immediately adjacent to a standard color chip. The best color match was made by trial and error. Records were kept in the standard Munsell notation for hue, value, and chroma; later hue was translated into a numerical code from 1 to 40 (Appendix D). When possible, color comparison was done in a darkened room. Lighting did not appear to affect perception of color, but making comparisons in a lighted room was difficult because of glare on the viewer. At best, the job of making color comparisons was tedious and fatiguing to the eyes.

Matte-finish Munsell soil color charts sufficed for evaluation of the Kodachrome slides. However, the extremely bright colors of the Ektachrome infrared were beyond the maximum chromas available even in the glossy-finish collection, and consistent interpretation by means of the table-top viewer was impossible. 4/ Therefore, a fourth interpreter used a projection technique to evaluate infrared photography for Seattle.

Color Evaluation: Projected Slides

Density matched slides of each subject for the two dates were projected simultaneously onto a silver screen in a partly darkened room by means of two 500-watt projectors. Lens-to-screen distance, adjusted to make both images the same size, was about 5 feet for Projector I and 6 feet for Projector II. Five interpretation subjects were selected on the September 1 slide for each of nine photo points; subjects were chosen to be typical of major classes of foliage (a stem in one instance) and identifiable on photography for both dates. The interpreter, sitting behind the projectors, held Munsell glossy color chips under a fluorescent desk lamp and in line with the interpretation subjects. Chip angle was adjusted to minimize reflection and present true color to the interpreter's eye. Color determinations were made with September 1 slides in Projector I and September 12 slides in Projector II; then the process was repeated with the projector-date combination reversed.

4/ A major source of difficulty appeared to be the need to compare back lighted, hence luminous, transparencies with opaque chips. The Remote Sensing Project at the Pacific Southwest Forest and Range Experiment Station solved this problem by photographing the chips and matching colors on the resulting transparencies with objects to be evaluated. This practice did not appear feasible in the present study because a suitable viewer was not available.

Examination of some slides suggested that color differences, if any, might result as much from exposure as from moisture stress or other effects of date. Therefore, the seven comparable pairs of normally exposed and over-exposed slides for both dates were interpreted through use of a single projector.

RESULTS

Effect of Calendar Date

Foliage color on Kodachrome transparencies varied significantly with calendar date. Analysis of variance usually showed a significant effect of date on each element of color for each interpretation at each site (table 2). Paucity of interpretable observations prevented analysis for infrared. Mean levels were sufficiently consistent on both films (tables 3 and 4) that statistical comparisons among interpreters were not made.

The means for each element of color on Kodachrome film, regardless of geographic location, followed seasonal trends defined by following linear regressions (figure 1):

Hue: $y = 28.66 - .053X$
Value: $y = 5.56 + .013X$
Chroma: $y = 5.22 + .013X$

The change in hue was from 2.5 GY (29) to 10 YR (24). Possibly a curvilinear regression or two separate linear regressions would fit the data somewhat better and show more realistically an early-season slow change in quality of greenness followed by a much faster late-season change toward yellow and yellow red. The slow increases in value and chroma denoted progressively less black and less neutral gray; however, the total changes were only from 5.6 to 7.0 in value and from 5.2 to 6.3 in chroma--so slight as to be imperceptible without careful comparison to a standard.

For viewed infrared transparencies, regressions of value and chroma on calendar date, using unweighted means by date and location, were significant (figure 2):

Value: $y = 4.78 + .022X$
Chroma: $y = 11.6 - .067X$

As with Kodachrome, value increased very gradually going from 4.8 at the start of the study to 6.5 at the end. Chroma, however, declined about three times as fast as value increased, going from 11.6 to 6.2, or from near absence of gray to more than average gray. No significant trend in hue occurred during the study. Successive averages for some points went counter to the trend; but when three or more dates were available for a given location, their averages roughly paralleled the regression line.

Table 2.--Significance 1/ of date and exposure effects on color ratings: Kodachrome II

	Seattle			Woodworth		Delta		Rich Mountain		Green Knob		
	Interpreter			Interpreter		Interpreter		Interpreter		Interpreter		
	I	II	III	I	II	I	II	I	II	I	II	III
Hue												
Date	ns	**	*	**	**	**	ns	**	**			
Exposure	ns	ns	ns	ns	ns	ns	ns	ns	ns			
Date X exp.	ns	ns	ns	ns	ns	ns	ns	ns	ns			
Value												
Date	*	**	*	**	**	**	**	**	**			
Exposure	**	*	**	**	**	*	**	ns	**			
Date X exp.	ns	ns	ns	*	ns	**	ns	ns	*			
Chroma												
Date	ns	**	ns	**	ns	**	*	**	**			
Exposure	ns	ns	ns	*	ns	ns	ns	ns				
Date X exp.	ns	ns	ns	ns	ns	ns	ns	ns				

Data inadequate for analysis

1/ ** = significant, .01 level; * = significant, .05 level; ns = non significant.

Table 3.--Mean Munsell color ratings on Kodachrome II film by calendar date, location, and interpreter 1/

Date	Place 2/	Hue 3/				Value				Chroma			
		I	II	III	Mean	I	II	III	Mean	I	II	III	Mean
8/20	RM	27.5	27.6		27.6	6.3	4.9		5.6	5.5	5.5		5.5
8/28	RM	27.1	27.1		27.1	7.2	5.3		6.2	6.1	5.7		5.9
8/29	WW	29.0	25.9		27.4	6.7	5.0		6.1	5.3	5.9		5.6
9/1	SEA	28.2	27.5	29.5	28.4	5.5	5.2	4.9	5.2	5.3	5.2	5.1	5.2
9/6	GK	31.5	27.0		29.2	5.0	4.5		4.8	4.3	4.3		4.3
9/12	SEA	27.4	26.3	28.2	27.3	6.1	6.0	5.4	5.8	5.3	6.2	5.7	5.7
9/22	GK	30.2	27.2		28.7	5.8	4.3		5.0	5.0	4.3		4.6
9/22	DL	28.4	25.7		27.0	7.8	6.4		7.1	6.2	6.7		6.4
9/26	WW	27.9	25.4		26.6	7.4	5.8		6.6	5.9	6.2		6.0
10/4	GK	27.8	26.8		27.3	6.2	5.2		5.7	6.0	4.3		5.2
10/12	RM	25.5	26.3		25.9	7.7	5.9		6.8	6.0	6.1		6.0
10/18	RM	25.4	24.9		25.2	7.9	7.2		7.6	5.1	6.7		5.9
10/21	DL	25.2	25.4		25.3	7.4	6.3		6.8	6.0	6.7		6.4
10/23	GK	20.7	23.2		21.9	6.2	5.3		5.8	7.0	6.3		6.6
10/23	WW	26.3	24.2		25.2	6.9	5.7		6.3	5.5	6.6		6.0
11/2	WW	25.6	24.9		25.2	7.1	5.9		6.5	6.0	7.0		6.5
11/6	DL	2.50	25.2		25.1	6.0	5.5		5.8	5.5	6.1		5.8

1/ Interpreters I and III were male, undergraduate students; Interpreter II was the project secretary.
2/ RM = Rich Mountain; WW = Woodworth Tower; SEA = Seattle; GK = Green Knob; DL = Delta Tower.
3/ See code, Appendix D.

Table 4.--Mean Munsell color ratings on Ektachrome Infrared film, by calendar date, location, and interpreter 1/

Date	Place 2/	Hue 3/				Value				Chroma			
		I	II	III	Mean	I	II	III	Mean	I	II	III	Mean
8/20	RM	17.4	17.6		17.5	5.7	5.3		5.5	10.5	10.3		10.4
8/28	RM	18.1	18.0		18.0	4.4	4.9		4.6	10.2	11.2		10.7
8/29	WW	18.3	18.2		18.2	5.2	5.2		5.2	11.6	12.9		12.2
9/1	SEA	18.7	18.4	17.2	18.1	4.9	5.2	5.1	5.1	7.3	9.6	8.0	8.3
9/6	GK	18.6	18.3		18.4	4.3	4.5		4.4	11.3	13.4		12.4
9/12	SEA	19.0	19.0	18.9	19.0	4.6	4.3	5.0	4.6	10.2	10.0	10.0	10.1
9/18	GK	18.0	18.5		18.2	5.0	4.8		4.9	12.0	14.0		13.0
9/22	DL	17.4	17.2		17.3	6.4	6.4		6.4	7.2	8.3		7.8
9/26	WW	18.3	17.6		18.0	6.4	6.5		6.4	10.3	11.4		10.8
10/4	GK	--	--	--	--	--	--		--	--	--		--
10/12	RM	19.4	20.3		19.8	6.5	6.3		6.4	6.3	7.7		7.0
10/18	RM	22.0	27.3		24.2	6.0	4.5		5.2	5.8	6.1		6.0
10/21	DL	18.8	18.6		18.7	7.0	7.3		7.2	6.4	5.1		5.8
10/23	GK	18.0	18.8		18.4	6.2	6.2		6.2	7.2	7.5		7.4
10/23	WW	18.6	18.1		18.4	6.8	5.7		6.2	7.7	10.2		9.0
11/2	WW	22.0	17.8		19.9	6.2	5.5		5.8	5.6	12.2		8.9
11/6	DL	17.8	18.5		18.2	7.2	6.0		6.6	4.8	3.2		4.0

1/ Interpreters I and III were male undergraduate college students; Interpreter II was the project secretary.
2/ RM = Rich Mountain; WW = Woodworth Tower; SEA = Seattle; GK = Green Knob; DL = Delta Tower.
3/ See code, Appendix D.

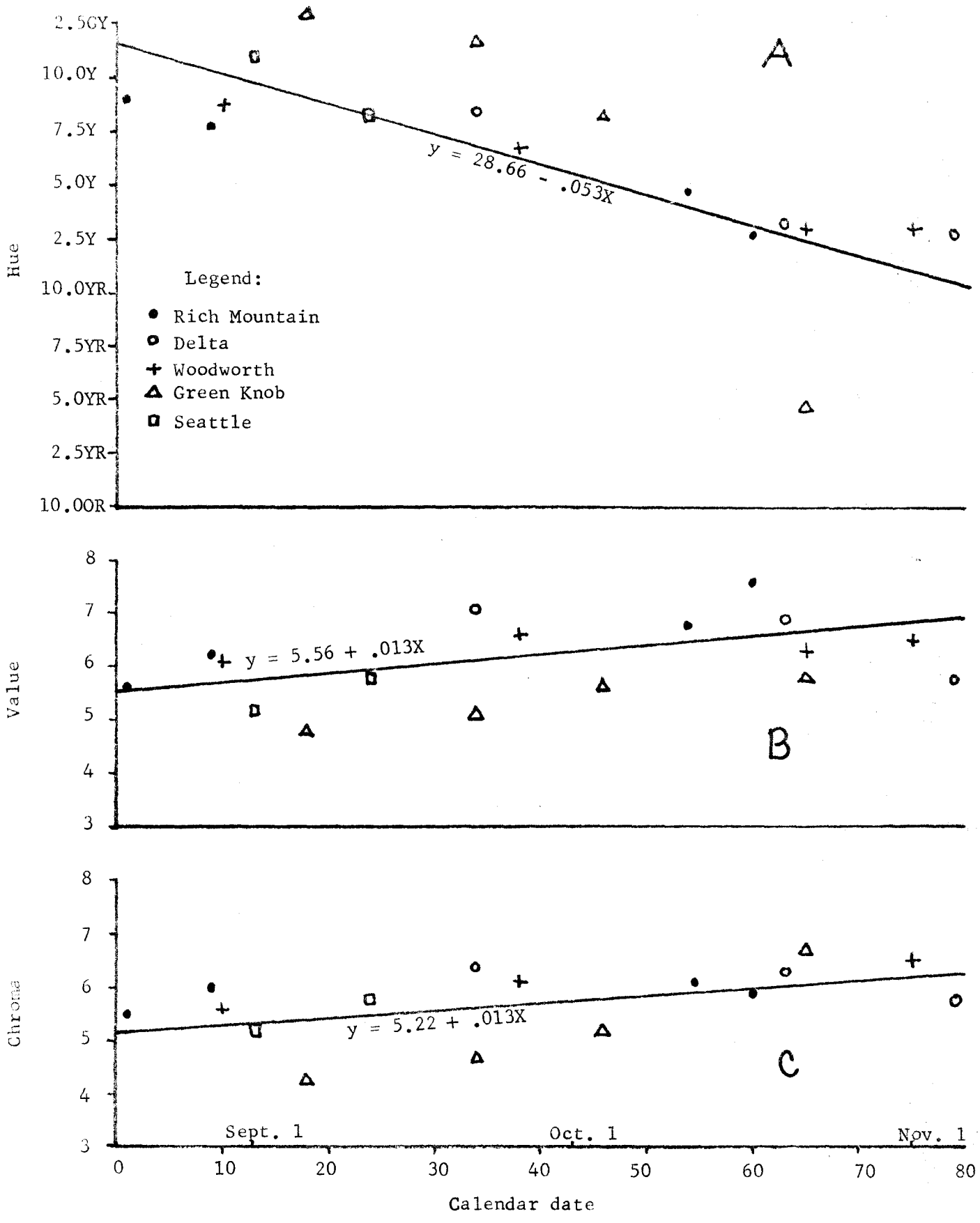

Figure 1.--Relation of hue (A), value (B), and chroma (C) of foliage color to calendar date: Kodachrome II film

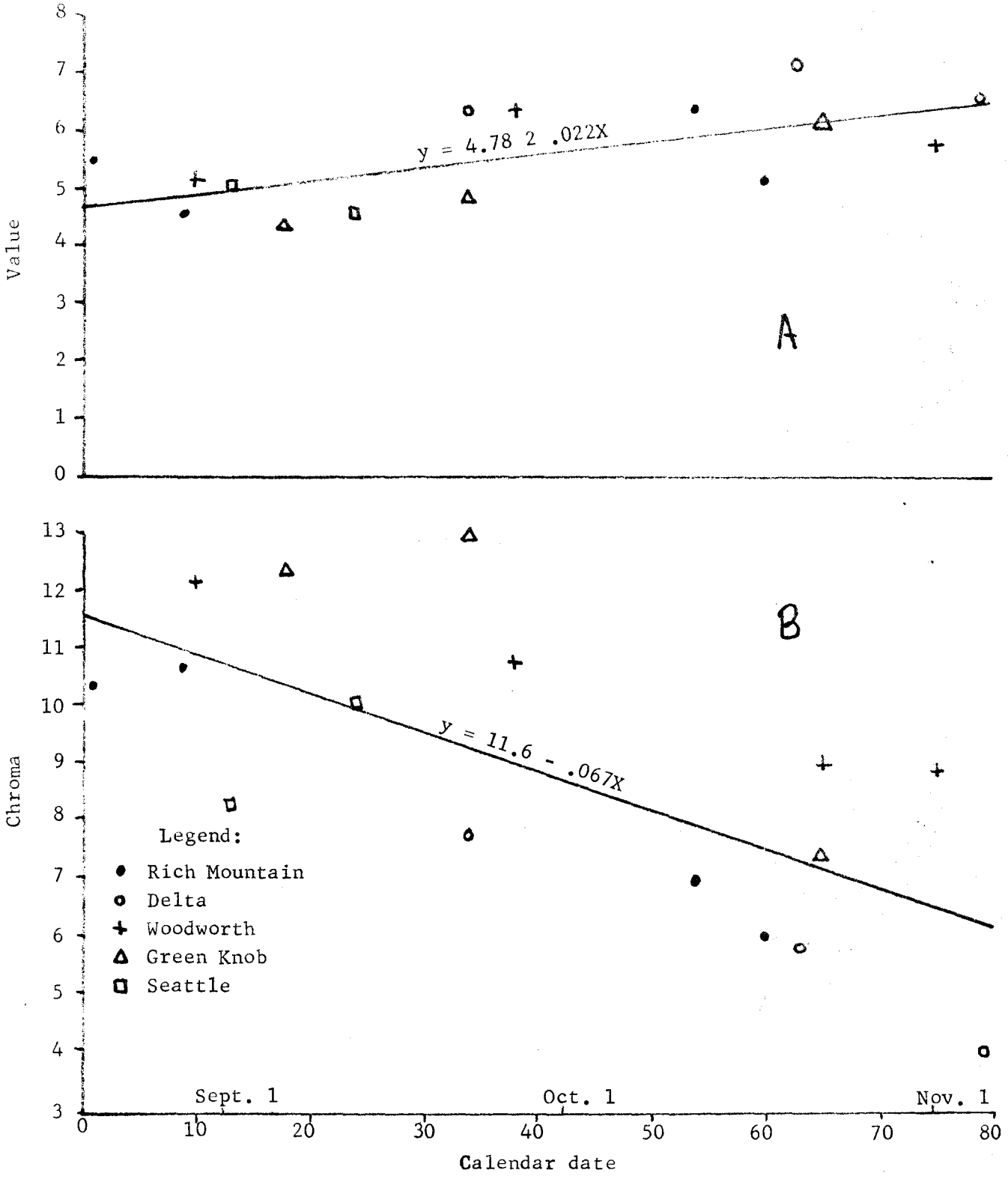

Figure 2.--Relation of value and chroma of foliage color to calendar date: Ektachrome Aero Infrared Film

Measurements on infrared projections for Seattle supported those obtained with the viewer. Mean color characteristics by dates were as follows:

	Hue	Value	Chroma
September 1 (dry)	11 RP	4.8	11.3
September 12 (moist)	2.8 R	5.1	12.5

Analysis of variance showed that the differences in hue, value, and chroma with date were all significant at the .01 level of probability. Value also differed significantly between projectors (.01 level), the lower (brighter) ratings being obtained with the projector that was nearer the screen. The interaction of date with photo point was significant for hue (.01 level) and chroma (.05 level). Overexposure significantly lowered value, i.e., increased brightness (.05 level), but had no effect on hue and chroma.

The indication is clear that mean hue and chroma differed significantly by date, possibly because of moisture levels in the vegetation. The difference in value apparently could have resulted from variations in exposure of the film and lighting of the subject. The differences in hue and chroma were less perceptible to the eye than to mathematical analysis. The Munsell chips closest to the above means are 10 RP 5/12 and 2.5 R 5/12; one can barely be distinguished from the other when they are placed side-by-side in good light. About the smallest differences that can be perceived readily are two steps of hue for a given chroma or two steps of chroma for a given hue. Hue difference between dates was two or more steps for both replications of only five out of 45 comparisons. In all five, the legitimacy of the difference appeared questionable because of variation in the angle at which light struck the foliage. Only one two-plus-step difference in chroma was consistent between replicates, and again direction of illumination was a possible contributor.

Effect of Moisture Stress

Degree of moisture stress, as indicated by extremes of Buildup Index, did not cause perceptible departure from seasonal trends of color change on Kodachrome (table 5). With only one exception, changes between dates with contrasting Buildup Index were in the direction that would be expected from calendar date; and differences in magnitude of color change were not proportional to magnitude of change in Buildup Index. Thus, Seattle experienced the biggest change in Buildup Index, from 221 on September 1 to 15 on September 12; and the changes in mean hue, value, and chroma slightly exceeded those indicated by regression (figure 1). However, the departure from the general trend amounted to only fractions of a step between available color standards: .5 for hue, .4 for value, .2 for chroma. So small a difference, even if statistically significant, could hardly be detected reliably because of the need for subjective interpolation between available standard color chips.

Table 5.--Comparison of actual color change between extremes of Buildup Index (BUI) with expected change due to calendar date

Location	Dates compared		BUI diff.	Color difference, high minus low BUI					
				Hue		Value		Chroma	
	Low BUI	High BUI		Actual	Expected	Act.	Exp.	Act.	Exp.
Kodachrome:									
Rich Mountain	10/18	10/12	38	+ .7	+ .3	- .8	-.1	+ .1	+ .1
Delta Tower	9/22	10/21	23	-1.7	-1.5	- .3	+.4	0	+ .4
Seattle	9/12	9/1	216	+1.1	+ .6	- .6	-.1	- .5	- .1
Woodworth Tower	8/29	9/26	38	- .8	-1.5	+ .5	+.2	+ .4	+ .2
do	11/2	10/23	32	0	+ .5	- .2	-.1	- .5	- .1
Green Knob	10/4	9/22	17	+1.4	+ .8	- .7	-.2	- .6	- .2
Infrared:									
Rich Mountain	10/18	10/12	38	-4.4	0	+1.2	-.1	+1.0	+ .4
Delta Tower	9/18	10/21	23	+1.4	0	+ .8	+.7	-2.0	-2.0
Seattle	9/12	9/1	216	- .9	0	+ .5	-.2	-1.8	+ .7
Woodworth Tower	8/29	9/26	38	- .2	0	+1.2	+.6	-1.4	-1.9
do	11/2	10/23	32	-1.5	0	+ .4	-.2	+ .1	+ .7
Green Knob			17	--		--		--	

On infrared transparencies, changes in value with Burning Index level were inconsistent as to both direction and magnitude when compared to expected change for the respective calendar date intervals; changes in chroma usually paralleled changes expected for the date intervals (table 5). As with Kodachrome, the data gave no reason to suspect an effect of moisture stress.

The change in chroma on Seattle infrared, as determined by both viewing and projecting, went more strongly counter to trend than any other color change. However, a single instance is not a proof of response to sudden relaxation of moisture stress.

Prediction of Leaf Abscission

The continuity of seasonal color trend showed no late-season abnormality that might relate to imminence of leaf abscission (figures 1 and 2). Change in trend was not noticeable even at the two locations (Delta and Woodworth) that experienced killing frost between the last two observation dates. Five out of ten color changes during the period followed were in the same direction as the trend, and five were contrary (including one instance of zero change).

CONCLUSIONS

The main well-supported conclusion is that neither natural color nor false color photography shows color changes in vegetation caused by moisture stress. Severe enough drought to provide a good test occurred at only one location, but there is no reason to believe that occurrence of the desired conditions at the other locations would have done more than add supporting evidence.

An increase in reflectance with time was to be expected (Olson and Good 1962), but how this might affect the elements of Munsell color characterizations was not foreseen, let alone the possibility that color changes at all locations would fall in the same continuum. The fact that colors in a wide variety of vegetation types, many degrees of latitude and longitude apart, followed the same seasonal trend lines suggests that the change may have resulted from change in light quality or sun angle. However there appears to be no reason why a change in light characteristics should increase chroma in natural color film and decrease it in false color film. Perhaps the apparent downward trend of chroma based on the rather few observations available from viewer interpretation was coincidental, for a significant increase in chroma was found when slides for Seattle were projected.

In general, there appears to be no future for colorimetric evaluation of moisture stress in vegetation at short range; further study of the subject should use infrared beyond 1000 millimicrons. This conclusion does not rule out the possibility of finding color differences that are visible from very high altitudes as from an earth orbital satellite. However, it does suggest that such differences, if they do occur, are much less distinct than the contrast between dry and recently wet areas clearly visible on Gemini photography. Thus remote optical surveillance appears unlikely to provide direct measurements of moisture stress but may permit a sort of "bookkeeping" approach based on frequency of wetting.

It is doubtful that photography with natural-color or available false-color film can decisively indicate that leaf abscission is imminent. A more sensitive study than this one would be required to obtain definite proof.

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APPENDIX A

SUBJECTS OF PHOTOGRAPHY

No.	Rich Mountain	Woodworth	Delta	Green Knob	Seattle
1	Pan.; N; mixed hardwood near, pine-hardwood far	C.u.; flowering dogwood	Pan.; W; mixed hardwoods	Pan.; SW	C.u.; blackberry backyard
2	Pan.; E; mixed hardwoods	C.u.; sweetgum	Pan.; SW; mixed oaks (Quercus spp.)	Pan.; NW	C.u.; Forsythia, backyard
3	Pan.; S; mixed hardwoods, pine	C.u.; red maple	Pan.; S; sycamore, sweetgum, et al.	Pan.; N	C.u; fireweed; backyard
4	Pan.; W; mixed hardwoods	C.u.; American beauty berry (French mulberry)	Pan.; SE; cottonwood mixed hardwoods	Pan.; NE	C.u.; mountain ash; backyard
5	C.u.; pokeberry, grape, smilax	C.u.; blackjack oak	C.u.; red maple sprouts	C.u.; rosebay rhododendron, N. of tower	Pan.; NW; red alder, Douglas-fir; backyard
6	C.u.; hickory	Pan.; azimuth 169	C.u.; vines	C.u.; scarlet oak, SW tower leg	Pan.; N; hardwoods, western hemlock; radar site
7	C.u.; white oak	Pan.; az. 225.5	C.u.; red mulberry sprouts	C.u.; Galax	Pan.; NE; mixed hardwoods; radar site
8	C.u.; white ash	Pan.; az. 280	C.u.; sycamore sprouts	C.u.; mixed clump of brush and sprouts	C.u.; Pacific dogwood; radar site
9	C.u.; sassafras	Pan.; az. 321.5	C.u.; cottonwood sprouts	C.u.; American mountain ash	C.u.; fireweed; radar site
10	C.u.; smooth sumac	Pan.; between az. 225 and 280	C.u.; sweet gum sprouts	C.u.; huckleberry	C.u.; willow; radar site
11	------	--------	C.u.; vines	Pan.; Blue Mtn. Range	C.u.; hemlock and Douglas-fir; radar site

APPENDIX B

INSTRUCTIONS FOR PHOTOGRAPHY

Delta Tower, Delta National Forest, Mississippi

Selection of Subjects and Photo Points

1. Take the four panoramic views in the attached sketch from the southwest corner of the landing below the cab.

2. Include horizon at extreme top of each photograph.

3. Along road near tower, select, for close-up photos, specimens of 5 species that retain their leaves until frost; some possibilities are red maple, red mulberry, sycamore, cottonwood, ash, grape. Specimens must have one side in full sun between 1000 and 1400.

4. Mark close-up specimens with flagging, and establish and mark photo point not more than 20 feet from each that permits including all or most of foliage of individual specimen or group.

5. Make notes, sketches, marks on the ground, etc., as necessary to get same field of view in all repeat close-ups.

Dates and Conditions of Photography

6. Take photos under the following seasonal and buildup conditions:

   a. Early August, low Buildup Index - preferably first clear day after rain of .50 inch or more. (Foliage should be dry in all photos.

   b. August 15 to September 15, Buildup Index at or near maximum expected this time of year.

   c. October 15 to November 15, Buildup Index at or near maximum likely to occur during this time of year.

   d. Same period, after moisture recharge - preferably first clear day after rain of .50 inch or more.

   e. Late autumn, leaf fall imminent; use frost forecast and own judgment in selecting day.

   f. At other times to get higher Buildup Index or other desired conditions.

7. Take all photos between 1000 and 1400 hours.

8. Select days when haze is least and cloud shadows cover not more than 25 percent of any panoramic view within 1/2 mile of the tower.

Photographic Technique

9. Use same camera for all photography (presumably Kodak "Signet").

10. Take one complete round of photos with Kodachrome II film and one with Ektachrome Aero Infrared on each photo day.

11. Use Skylight filter for all Kodachrome and Wratten 12 (yellow) filter for all Infrared photography.

12. Use shutter speed no slower than 1/60 second and f-stop number no lower than 5.6. Use exposure meter to determine correct exposure for each photo, based on ASA film speed of 25 for Kodachrome and 100 for Ektachrome Infrared. Approximate settings for panoramic views in full sun are:

Desired exposure	Kodachrome	Infrared
Normal	1/50 or 1/60, f/11	1/100, f/16
1-stop over-exposure	1/50 or 1/60, f/8	1/100, f/11

13. Take photos in approximately the following order:

Kodachrome: close-ups, exposure shown by meter
close-ups, 1-stop over-exposure
panoramic views, exposure shown by meter
panoramic views, 1-stop over-exposure

Infrared: panoramic views, exposure shown by meter
panoramic views, 1-stop over-exposure
close-ups, exposure shown by meter
close-ups, 1-stop over-exposure

14. Photograph a card showing date and location (e.g., 8/12--DNF) in at least one exposure on each roll of film.

15. Use leftover exposure to correct errors or to take additional subjects of interest, if desired. Use surplus rolls for subjects of interest related to the study.

16. Record photos on form provided; make notes as necessary.

17. Note species of conspicuous trees in panoramic views on sketches.

Handling of Film

18. Keep unexposed film under refrigeration, or at least in place where maximum temperature will not exceed 75°F.

19. Take film from storage not more than 24 hours before it will be used; replace exposed film in can and return to same storage promptly after exposure.

20. When all photography is completed, send all exposed film, photographic records, and notes to Fuel Appraisal Systems Project, U.S. Forest Service, 4507 University Way N.E., Seattle, Washington 98105, by registered air mail.

Panoramic Photographs

Delta Tower, Delta National Forest, Mississippi

All photos will be taken from the southwest corner of the landing below the cab, as diagrammed below:

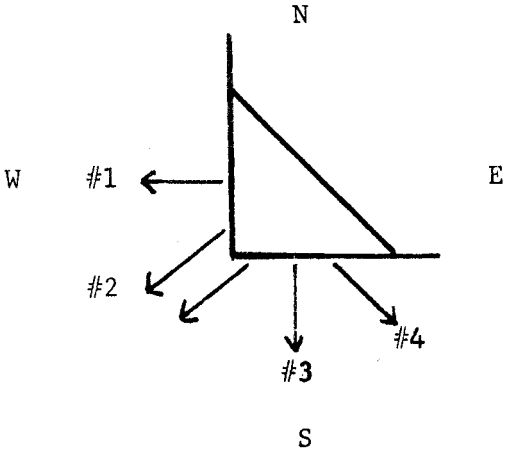


Photo #1

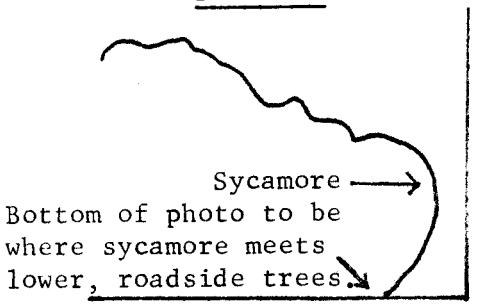


Photo #2

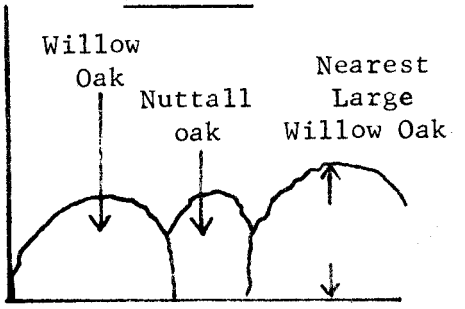


Photo #3

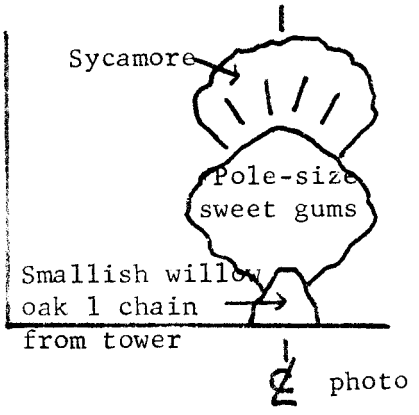
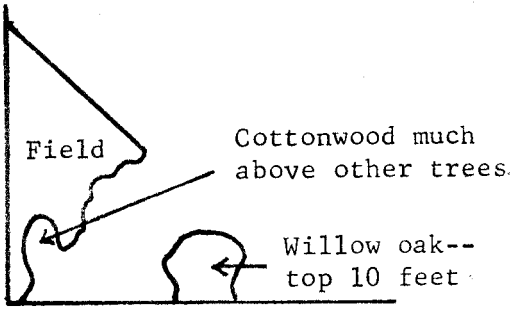


Photo #4



APPENDIX C

INSTRUCTIONS FOR SELECTING COLOR COMPARISON POINTS

1. Examine Kodachrome slides in a viewer using the same viewer in the same location for all selection.

2. Use ambient lighting sufficiently subdued that colors and other detail on transparencies stand out clearly. Use the same lighting for all selections.

3. Prepare a 7 x 10'-square rectangular grid to a scale that exactly covers a 35-mm. color transparency as displayed in the desired viewer. Use letters A to F for short-side coordinates, numerals 1 to 10 for long-side coordinates.

4. Select and designate by grid coordinates up to 3 comparison points at each photo point on the first series of slides (by date) at each study location in accordance with the following criteria:

   a. Good lighting. Ordinarily this means in full sunlight and without strong backlighting. For close-up subjects, some shade and backlighting will have to be accepted.

   b. Solid color. A single color must predominate sufficiently to characterize the point. Some mottling will have to be accepted because of shadows and variation in the angle at which sunlight strikes different leaves.

   c. Representative color. In panoramic views, the color should be one that characterizes a distinct, relatively large or notably prominent segment of the vegetation in view. On close-ups, comparison points should include healthy foliage in a natural attitude; i.e., usually seen from above. On views that contain large enough areas of contrasting colors, one point per color, up to a total of 3, is desirable. See Munsell color charts to check for contrast and consistency.

   d. Size. Points must be at least as large as one square of the identification grid.

   e. Duplication. On close-ups and rather homogeneous panoramas, one or two duplicate points should be designated to ensure comparability of lighting with later photography.

5. Check visibility and lighting of color comparison points selected against each subsequent series of slides, and amend selections as necessary to provide that the same points are used throughout the study.

6. Record the coordinates of the color comparison points on the form provided.

7. Submit final selections to review by study leader.

8. Examine Ektachrome infrared slides and select color comparison points in the same manner.

9. Use the same criteria as for Kodachrome, but (1) avoid "saturated" (i.e., strong, bright red) areas, and (2) select the same points as for Kodachrome where suitable.

APPENDIX D

CODE TABLE FOR HUE

Hue	Code
2.5 B	01
5.0 B	02
7.5 B	03
10. B	04
2.5 PB	05
5.0 PB	06
7.5 PB	07
10. PB	08
2.5 P	09
5.0 P	10
7.5 P	11
10. P	12
2.5 RP	13
5.0 RP	14
7.5 RP	15
10. RP	16
2.5 R	17
5.0 R	18
7.5 R	19
10. R	20
2.5 YR	21
5.0 YR	22
7.5 YR	23
10. YR	24
2.5 Y	25
5.0 Y	26
7.5 Y	27
10. Y	28
2.5 GY	29
5.0 GY	30
7.5 GY	31
10. GY	32
2.5 G	33
5.0 G	34
7.5 G	35
10. G	36
2.5 BG	37
5.0 BG	38
7.5 BG	39
10. BG	40

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